# CHAPTER 6

# FIELD PILE TESTS

## 6-1. General.

a. A field pile test program will generally consist of two types of procedures: load tests to determine the load capacity of service piles; and driving selected types of piles with selected types of hammers and recording data on driveability. These tests may be conducted separately or, as is more common, concurrently. The latter can be accomplished by simply recording the necessary data during the driving of the piles that will be load tested. Field pile tests are performed to verify or predict driving conditions and/or load capacity of service piles at the construction site. Verification is the process of test driving and loading the designated piles to predetermined static loads to confirm prior design capacity calculations that were based on static or dynamic type equations, previous experience, or empirical methods. This process is used primarily only to confirm the load capacity and driveability of the selected pile as service piles. Prediction is the process of test driving various piles or of loading test piles in increments to failure to determine the length, type, and ultimate capacity of the service piles at the construction site. Prediction tests differ from the verification process in that these tests will be utilized for design purposes. Therefore, the final pile size, type, and lengths generally have not yet been determined when these tests are conducted. Prediction type tests are more common to large or major structures where changes in pile lengths, size, type, or method of installation could result in significant economic savings due to the large number of piles involved.

b. A field load test on test piles may consist of two types, axial and/or lateral. These tests may be performed on single piles or pile groups.

## 6-2. Decision Process.

Pile tests are not practical or economically feasible under certain circumstances, but they are always technically desirable. In the initial design stages, as soon as the requirement for a pile foundation is confirmed, several factors should be considered and evaluated to govern the decision process.

a. Factors for Consideration. Appropriate evaluations of the following factors should be included in the reconnaissance study and updated in each successive report stage for the project.

(1) Engineering. The size, type, and importance of the proposed structure, type of subsurface conditions, and economics are engineering factors. Size and economics are directly related; since pile tests are relatively expensive, a structure requiring a small number of piles could not normally justify the expense of a pile test. The type and functional importance of a structure could offset the added cost of a pile test program for a complex foundation when the consequences of a potential failure would be catastrophic, especially if the information obtained from subsurface investigations indicated unusual conditions that would be difficult to interpret. The costs of pile tests should be compared with the potential project savings from basing the foundation design on the test results with reduced safety factors. Also, when a requirement for a field pile test program has been established, the

technical aspects, scheduling, estimated costs and any intangible benefits of the two following alternatives should be evaluated:

(a) Perform pile tests by separate contract and complete the foundation design prior to award of the construction contract.

(b) Award a construction contract with a selected type or types of piles and estimate pile lengths with a pile test program included to determine the actual pile lengths required.

(2) Budget and Schedules. During the reconnaissance study phase of a new project, a preliminary foundation evaluation for each potential project site is required to determine the need for pile foundations. For each potential site that needs a pile foundation, initial cost estimates and schedules must identify and include resources for necessary site investigations to provide adequate data for proper site selection and estimated costs for the feasibility study phase. The feasibility report should include a recommended site, preliminary alternate foundation designs, and the scope of required pile tests, etc. Required resources, schedules and cost estimates must be revised for each successive report phase to reflect the current design status of each project component. If a separate contract for pile tests is recommended prior to award of the construction contract, appropriate adjustments must be made to the schedules and budgeted funds.

(3) Available Test Site. Consideration has to be given to the timing of the test pile program in relation to the construction schedule. The test pile program may be a separate contract awarded and completed before construction begins. The advantages of this approach are many: the pile size, type, lengths, and preferred installation method can be determined before construction of the project; any problems with the pile test and potential problems with design revealed by the pile tests may be resolved prior to construction when they are more likely to be less costly. The disadvantages of this approach are: the design schedule is extended to allow time for the separate operations; the test conditions may not closely simulate design assumptions since excavation, water conditions, fill, etc. may not necessarily match construction conditions; and additional problems may develop if different contractors and/or equipment are used during the testing program and driving the service piles. These advantages and disadvantages must be evaluated in relation to the site availability.

(4) Site access. If the decision is made to conduct the testing program during the construction process, the scheduling of the test program becomes important. The tests must be conducted early in the construction process, since the contractor generally must await the outcome of the tests before ordering the service piles. However, the testing cannot be scheduled too early, since the test site needs to be prepared and accessible.

b. Proof Test. In the overall design process, field tests are normally scheduled after some estimate of pile capacity and driveability has been made. The driveability of piles is generally evaluated early in the design process, usually in the General Design Memorandum stage when basic design decisions are being made relative to the foundation. Also at this point, an estimate of pile capacity is made. During the Feature Design Memorandum phase of design, a more accurate prediction of pile capacity and/or required pile lengths is made, and a test pile program is established to verify the design assumptions and pile driveability. The final stage of the design process is the actual testing program. As discussed earlier, the results of this testing program may be used solely to verify the predicted pile capacities, and/or required pile lengths, or may be used as an extension of the design process by changing the pile size, type, lengths, or installation method of the service piles as required. Refer to preceding paragraphs relative to the timing of field tests with respect to construction, site availability, site access, and potential problems.

6-3. Axial Load Test.

a. Compression.

(1) General. The load test should basically conform to the procedures contained in ASTM D1143 (Item 25). This standard is recommended as a guide and should be modified as required to satisfy individual project requirements. Important aspects of the test are discussed in the following paragraphs. Information on conducting dynamic load tests may be obtained from the Geotechnical Laboratory of the US Army Engineer Waterways Experiment Station in Vicksburg, MS.

(2) Applying Load. In the past, test loads were generally applied by placing dead weight as a vertical load directly on top of the piles to be tested. In current practice, loads are applied by jacking (with a hydraulic ram) against a stable, loaded platform, or against a test frame anchored to reaction piles. Typical loading arrangements are illustrated in the referenced ASTM D1143 Standard. If reaction piles are used, various studies have indicated that the distance between these piles and the test piles should be a minimum of at least 5 pile diameters for nondisplacement piles to up to 10 diameters for displacement piles.

(3) Jacks and Load Cells. Most load tests are conducted with hydraulic jacks to apply the load, and load cells to measure the load. The hydraulic jack ram or the load cell should have a spherical head to minimize eccentricity between the jack and the loading frame. Both the jack (with pressure gage) and the load cell should be calibrated by a qualified lab to include calibration curves. During the load test both the load cell and the jack pressure gage should be read and compared. In the event it is later discovered or determined that the load cell has malfunctioned, the pressure gage readings will then be available. It is also important during the test to continually monitor the load cell to ensure that the load increment is being maintained at a constant value. The load has a tendency to decrease due to pile penetration into the ground, deflection of the test beams, and loss of hydraulic fluid from leaking valves, etc.

(4) Measuring Devices. Settlement measurement devices are usually dial gages, with some other independent system as a backup. It is important to protect these devices from the weather, since direct sunlight can significantly affect the readings. The ASTM D1143 Standard illustrates a typical installation. Consideration should also be given to measuring the lateral movement of the pile during the test procedure to detect eccentric loading conditions. All dial gages should be calibrated by a qualified lab.

(5) Instrumentation. If the distribution of the pile load along its embedded length is required, and not merely the total or ultimate load, the pile

should be instrumented with telltales or strain gages. All instrumentation should be tested after the pile is driven to verify that it is still functioning properly. Refer to the ASTM D1143 Standard for possible telltale arrangements. A strain-gage system may also be used. These systems, although generally more expensive, but can yield excellent results if properly installed and read.

(6) Net Settlement. Provisions should be made during the pile tests to determine the net settlement of the pile (i.e. the total settlement less the elastic compression of the pile and soil). This is required to develop a net settlement (i.e. the pile tip movement) versus load curve to determine pile capacity. Net settlement may be determined by loading and unloading the pile in cycles (see the ASTM D1143-81 Standard (Item 25)) by employing a telltale located at the pile tip.

(7) Technical Specifications. Plans and specifications for the pile test should be developed generally in accordance with the referenced ASTM D1143 Standard and should be specifically modified as needed to satisfy the particular project requirements and subsurface conditions. Technical specifications should include the following as a minimum:

(a) Type, size, length, and location of pile(s) to be tested

(b) Size and capacity of pile driving equipment

(c) Driving criteria and any special installation methods required

(d) Types of tests to be conducted and maximum testing capacity necessary

(e) Required testing equipment and instrumentation, including calibration, to be furnished

(f) Testing procedures to be followed

(g) Data to be recorded and reported

(h) Report format to be followed

(i) Provisions for additional tests

(j) Payment schedule and schedule of bid items

b. Tension.

(1) General. The load test should basically conform to the procedures contained in ASTM D3689-78 (Item 23). This standard is recommended as a guide, and should be modified as required to satisfy individual project requirements. Important aspects of the test are discussed in the following paragraphs.

(2) Testing. Tension tests are often conducted on piles which have previously been tested in axial compression. Some advantages to this are: a direct comparison of tension and compression on the same subsurface profile, cost savings in not having to drive an additional pile, and information on

piles that must function in both tension and compression under operating conditions. Some disadvantages are: residual stresses may significantly affect the results, remolding of the soil may take place during the first test, and a waiting period is generally required between the compression and tension test. Appropriate references should be consulted relative to residual stresses and the necessary waiting period (paragraph 6-3d(5)).

(3) Other Considerations. The same aspects of compression tests need to be considered for conducting tension tests: applying the load, use of jacks, load cells, measuring devices and instrumentation, net settlement, and technical specifications. Paragraph 6-3a and the referenced ASTM Standards must be referred to for compression and tension tests. Interpretation of test results is described in paragraph 6-3e.

c. Quick Load Tests.

(1) General. The load test outlined in the referenced ASTM D1143 Standard (Item 25) can be described as a slow, maintained-load test. The duration of this procedure can exceed 70 hours or longer, especially when cyclic loading is included. There are alternatives to this "slow" test when time is of the essence, or when a quick method is needed to verify service pile capacities that were projected from test piles using the slow, maintained-load method. These alternatives are the constant-rate-of-penetration test (CRP), and the quick, maintained-load test. Both of these methods are permissible options described in the referenced ASTM Standard (Item 25). The CRP test appears to be seldom used in this country. The quick, maintained-load test is often used, although its format has many variations.

(2) CRP Test. In a CRP test, the load is applied to cause the pile head to settle at a predetermined constant rate, usually in the vicinity of 0.01 inch per minute to 0.1 inch per minute, depending on whether the subsurface conditions are cohesive or granular, respectively. The duration of the test is usually 1 to 4 hours, depending on the variation used. The particular advantage of the CRP test is that it can be conducted in less than one working day. A disadvantage is that ordinary pumps with pressure holding devices like those used for "slow" tests are difficult to use for the CRP test. A more suitable pump is one that can provide a constant, nonpulsing flow of oil. Appropriate references should be consulted relative to the CRP test, if it is utilized.

(3) Quick Maintained-Load Test. In this test, the load is applied in increments of about 10 percent of the proposed design load and maintained for a constant time interval, usually about 2 to 15 minutes. The duration of this test will generally be about 45 minutes to 2 hours, again depending on the variation selected. The advantage of this test, like the CRP test, is that it can be completed in less than 1 working day. Also, unlike the CRP test, no special equipment is required. Appropriate references should be studied if this test is utilized.

(4) Other Considerations. The same aspects of axial load testing discussed in paragraphs 6-3a and 6-3b, and the referenced ASTM Standards (Items 23 and 25), need to be considered for "quick" tests. These include applying the load, use of jacks, load cells, measuring devices and

instrumentation, net settlement, and technical specifications, when applicable. Refer to paragraph 6-3e for interpretation of test results.

d. General Considerations.

(1) Reaction Pile Effects. If a pile is loaded by jacking against reaction piles, the effects of the reaction piles on the test pile (increase or decrease in intergranular pressures) should be taken into consideration.

(2) Load to Failure. Test piles should be loaded to failure when possible, as this test yields valuable information to the designer. Ideally, care must be taken as failure is approached to collect data more frequently than at sub-failure loads and to maintain the same rate of loading employed before reaching failure.

(3) Pile Driving Analyzer or Quick Tests. On a large or significant structure, consideration should be given to using a pile driving analyzer and/or performing quick tests in conjunction with the regular test pile program. The additional information provided (hammer efficiency, etc.) could aid the designer in evaluating the adequacy of the service piles, should unexpected problems develop, without having to conduct additional and costly conventional pile testing. In conjunction with the pile driving analyzer, a wave equation analysis should be performed prior to the pile test to calibrate the wave equation analysis with the results of the pile driving analyzer. Refer to Chapter 5, paragraph 5-3a for a discussion of the wave equation analysis. The pile driving analyzer is discussed in paragraph 5-4a. On a smaller or less significant project, the use of a pile driving analyzer may not be economically justified. However, a wave equation analysis is very simple to run and should be performed.

(4) Location of Test Site. Test piles should be located as near as possible to a boring. In many instances, circumstances warrant that a boring be taken specifically for the pile test. Piezometric data should also be available. Conditions measured by the piezometers should be correlated with design/operating conditions.

(5) Waiting Period. The waiting period between the driving of the test piles and the pile load test should allow sufficient time for dissipation of excess pore water pressures resulting from the pile driving operation. If sufficient time is not allowed, the test results may mislead the engineer to select pile capacities that are lower than the actual values. This waiting period is a function of many interrelated complex factors and can significantly affect the results of the pile test. Generally, piles driven into cohesive foundations require more time than those placed in granular materials. For the cohesive case, 14 days is recommended. An absolute minimum of 7 days is required. The referenced ASTM Standards (Items 23 and 25) have some guidance in this area. Other references should be studied before writing the technical specifications, if applicable. For cast-in-place concrete piles, the waiting period should consider the curing time and resulting strength of the concrete, and the possible effects of concrete hydration on the soil surrounding the pile.

(6) Reporting Test Results. Data from the load tests should be recorded and reported in an orderly fashion. Items to be included are listed in the referenced ASTM Standards (choose only those that are applicable to the

project requirements). Results will often be used to estimate axial capacity and/or driving characteristics for other projects with similar subsurface conditions, or expansion/modification of the existing project. Thus, it is important to maintain records in a manner that will be useful and easy to interpret at some future date.

e. Interpretation of Results. The interpretation of the tests results generally involves two phases, analyzing the actual test data, and application of the final test results to the overall design of the service piles and the structure.

(1) Axial Capacity Determination Method. There are many empirical and arbitrary methods available to determine the axial capacity of a pile from load test data. Some of these methods are contained in bibliographical material found in Appendix A. It should be noted that the methods described in Table 6-1 are for informational purposes only, are not necessarily current practice, nor necessarily recommended by the respective listed sources. The methods are listed merely to indicate historical practice and the diversity of philosophy.

(a) Corps of Engineers Method. The following method has often been used by the Corps of Engineers and has merit: determine the load that causes a movement of 0.25 inch on the net settlement curve; determine the load that corresponds to the point at which the settlement curve has a significant change in slope (commonly called the tangent method); and determine the load that corresponds to the point on the curves that has a slope of 0.01 inch per ton. The average of the three loads determined in this manner would be considered the ultimate axial capacity of the pile. If one of these three procedures yields a value that differs significantly from the other two, judgment should be used before including or excluding this value from the average. A suitable factor of safety should be applied to the resulting axial pile capacity. See Figure 6-1 for an example of this method.

(b) Davisson Method. A commonly used method to evaluate pile tests is one suggested by Davisson (Item 30). The failure load is defined as the point at which the movement of the pile butt exceeds the elastic compression of the pile by 0.15 inch plus a factor (B/120) that is a function of pile diameter (B). The advantage of this method is the inclusion of physical pile size (length and diameter) in the definition of failure load. This failure load should exceed two times the allowable load.

(2) Foundation Considerations. Once the axial capacity of the pile is established, the next step is to interpret this information relative to the known foundation conditions, the nature of the loads on the structure, the size and significance of the structure, and any other pertinent information.

(a) Group Effects. It should be noted that the results of a single pile test may not indicate the capacity of a group of similar piles. The effects of group loading are experienced much deeper in the foundation than those of the single pile. Group loading may result in the consolidation of a soft clay layer that would otherwise be unaffected by a single pile loaded to the same unit load.

(b) Settlement. A pile test on a single pile will generally yield sufficient data to determine the failure load or bearing capacity. However, the

Table 6-1

Methods of Pile Load Test Interpretation

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1. Limiting Total Butt Settlement

    a. 1.0 in. (Holland)
    b. 10% of tip diameter (United Kingdom)
    c. Elastic settlement + D/30 (Canada)

2. Limiting Plastic Settlement

    a. 0.25 in. (AASHO, N.Y. State, Louisiana)
    b. 0.5 in. (Boston) [complete relaxation of pile assumed]

3. Limiting Ratio: Plastic/Elastic Settlement

    1.5 (Christiani and Nielson of Denmark)

4. Limiting Ratio: Settlement/Unit Load

    a. Total 0.01 in./ton (California, Chicago)
    b. Incremental 0.03 in./ton (Ohio)
    0.05 in./ton (Raymond International)

5. Limiting Ratio: Plastic Settlement/Unit Load

    a. Total 0.01 in./ton (N.Y. City)
    b. Incremental 0.003 in./ton (Raymond International)

6. Load-Settlement Curve Interpretation

    a. Maximum curvature - plot log total settlement vs log load; choose point of maximum curvature
    b. Tangents - plot tangents to general slopes of upper and lower portion of curves; observe point of intersection
    c. Break point - observe point at which plastic settlement curve breaks sharply; observe point at which gross settlement curve breaks sharply (Los Angeles)

7. Plunge

    Find loading at which the pile "plunges," (i.e., the load increment could not be maintained after pile penetration was greater than 0.2 B).

8. Texas Quick Load

    Construct tangent to initial slope of the load vs gross settlement curve; construct tangent to lower portion of the load vs gross settlement curve at 0.05 in./ton slope; the intersection of the two tangent lines is the "ultimate bearing capacity."

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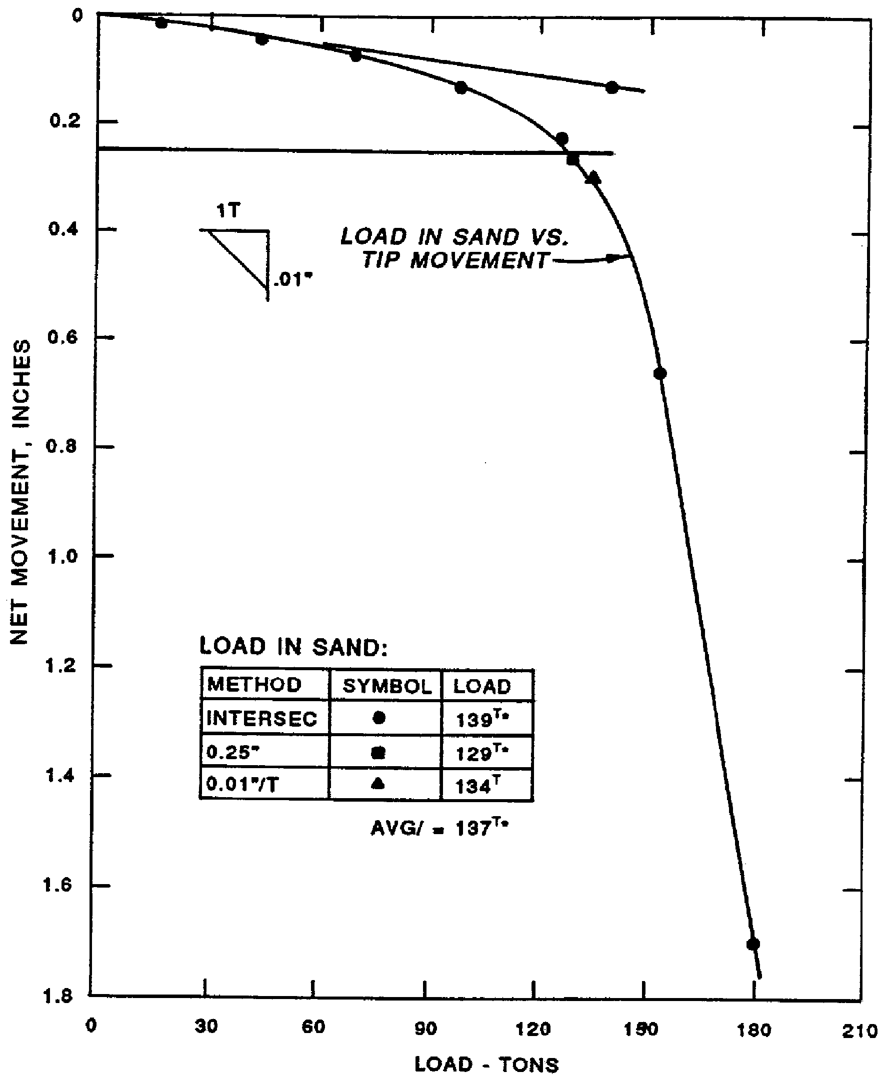


Figure 6-1. Corps of Engineers method for determining axial capacity

pile test does not provide data relative to the settlement of the pile under operating conditions in a cohesive foundation. The load test is generally conducted in too short a time frame to enable clays to consolidate. Therefore, a significant amount of settlement may occur during the life of the structure--settlement that would not be predicted by the pile test. For granular foundations however, the pile test does generally yield adequate data on bearing capacity and settlement.

(c) Operating Conditions. Consideration should be given to the possibility that the test pile conditions may differ significantly from the operating conditions for the structure. Examples are: potential uplift in pervious strata that are dewatered during the pile test; backfill or excavation after the pile test; the nature of the loading on the piles (static, dynamic, long term, short term, etc.); battered service piles in lieu of vertical test piles; lateral loading effects; and negative skin friction.

(d) Driving Effects. The effects of driving many service piles may change the conditions existing during the test. Piles driven into a granular material may densify the foundation and increase pile capacity, while piles driven into a sensitive cohesive foundation may decrease pile capacity.

(e) Layered Foundations. Layered foundations may cause service piles to perform differently than indicated by test piles. During a test pile loading, a cohesive layer may be supporting the piles. During the life of the service pile, this same cohesive layer may consolidate under the load, and transfer the load to another soil layer not stressed during the pile test. The service pile may also shift from being a friction pile to being more of an end bearing pile under similar conditions.

(f) Residual Stresses. Residual stresses that may be present during the pile test may be significant and must be considered. These stresses may be detected by instrumenting the piles and taking readings prior to and just after driving. If residual stresses are present, it may be necessary to consider these stresses when evaluating the distribution of the tip and skin resistance.

(g) Tip Elevations. Finally, if the pile tests are used to project pile capacity for tip elevations other than those tested, caution should be exercised. In a complex or layered foundation, selecting a tip elevation for the service piles different from the test piles may possibly change the pile capacity to values other than those projected by the test. As an example, shortening the service piles may place the tips above a firm bearing stratum into a soft clay layer. In addition to a loss in bearing capacity, this clay layer may consolidate over time and cause a transfer of the pile load to another stratum. Lengthening the service piles may cause similar problems and actually reduce the load capacity of the service piles if the tips are placed below a firm bearing stratum. Also, extending tips deeper into a firmer bearing stratum may cause driving problems requiring the use of jetting, predrilling, etc. These techniques could significantly alter the load capacity of the service piles relative to the values revealed by the test pile program and should be considered in setting tip elevations for service piles.

6-4. Monotonic Lateral Load Test.

a. General. The main purpose of a lateral load test is to verify the values of $n_h$ or $E_s$ used in design. The value of the cyclic reduction factor used in design can also be verified if the test pile is cyclicly loaded for approximately 100 cycles. The basis for conducting a lateral load test should be ASTM D3966-81 (Item 24) modified to satisfy the specific project requirements.

b. Applying Load. A lateral load test is most easily conducted by jacking one pile against another. In this manner, two lateral load tests can be conducted simultaneously. When applying the lateral load to the pile, it is important to apply the load at the ground surface with no restraint at the pile head. This gives a free-head pile boundary condition and makes the data easy to reduce to curves of $n_h$ or $E_s$ versus pile top deflection. The loads are applied with a hydraulic jack. A spherical bearing head should be used to minimize eccentric loading.

c. Instrumentation. The minimum amount of instrumentation needed would be dial gages to measure lateral pile head deflection and a load cell to measure applied load. A load cell should be used to measure load instead of the pressure gage on the jack because pressure gage measurements are known to be inaccurate. Additional instrumentation could consist of another level of dial gages so the slope at the top of the pile can be calculated, and an inclinometer for the full length of the pile so that lateral pile deflection at any depth along the pile can be calculated. If p-y curves are necessary for the pile foundation design, then strain gages along the pile to measure bending moment are needed. However, since the purpose of lateral load tests described in this section is to verify or determine pile-soil properties to be used in the normal design of a civil works project, the use of strain gages along the length of the pile is not recommended. Accurate strain-gage data are difficult to obtain and only of value in research work where p-y curves are being developed. Strain gages should not be installed by construction contractors because they do not have the necessary expertise to install them. If strain gages are used, consultants experienced in their use should be hired to install them, and record and reduce the data.

d. General Considerations.

(1) Groundwater. The location of the ground-water table has an effect on how laterally loaded piles behave. For this reason it is important to have the groundwater table during testing as near as possible to the level that will exist during operation of the structure.

(2) Load to Failure. It is important to carry the load test to failure. Failure is defined as when the incremental loading can not be maintained.

(3) Location of Test Site. Piles should be located as near to the site of the structure as possible and in similar materials.

(4) Reporting Test Results. Accurate records should be made of the pile installation, of load testing, and of the load test data to document the test.

6-5. Cyclic Lateral Load Test.

a. General. The main purpose of a cyclic lateral load test is to verify the value of the cyclic loading reduction factor ($R_c$) used in design. Approximately 100 cycles of load should be used in a cyclic load test. The load test should be conducted according to ASTM D3966-81 (Item 24) modified as necessary for cyclic loading and specific project requirements. The instrumentation, equipment, and test layout necessary for conducting the cyclic load test is similar to that required for the monotonic lateral load test.

b. Procedure. Generally the cyclic lateral load test would be done in combination with the monotonic lateral load test on the same piles. Since repeated testing of the same pile can cause permanent nonrecoverable deformations in the soil, the sequence of testing is important. One sequence for doing the monotonic and cyclic lateral load test is outlined as follows: The designer must first select the load level of the cyclic test. This may be done from a known load level applied to the pile founded monoliths or a deflection criterion. A deflection criterion would consist of loading the load test piles to a predetermined deflection and then using that load level for the cyclic load test. Using the cyclic load level, the test piles would be cyclically loaded from zero loading to the load level of the cyclic load test. This cyclic loading procedure would be repeated for the number of cycles required. Dial gage readings of lateral deflection of the pile head should be made at a minimum at each zero load level and at each maximum cyclic load level. Additional dial gage readings can be made as necessary. After the last cycle of cyclic loading has been released the test piles should then be loaded laterally to failure. That portion of the final cycle of load to failure above the cyclic test load can be superimposed on the initial cycle of loading to get the lateral load-deflection curve of the piles to failure.